Transport Processes in the Coastal Atmospheric Boundary Layer

Michael Tjernström
Department of Meteorology
Stockholm University
S-106 91 Stockholm
Sweden
phone: (+46 8) 16 31 10 fax: (+46 8) 15 71 85 email: michaelt@misu.su.se

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http://misu.su.se/~michaelt/home.html

LONG-TERM GOALS

To better understand, and thus be able to better predict, the transport of different constituents and air-mass properties in the marine atmospheric boundary (MBL) layer and between the MBL and the near-coast land. This transport may in many cases be due to mesoscale flow systems at locations along mountainous coastlines or to boundary layer processes at the coast. The transported constituents may be properties of the marine boundary layer air, e.g. humidity, air pollution or aerosols – the latter both of natural and man-made origin. In particular I am interested in the cross-coast mixing potential. By this I mean the probability of finding properties from the marine environment at inland locations or matter released over the continent ending up in the marine environment.

OBJECTIVES

The dispersion and mixing of aerosols and other species in the coastal zone is influenced by meteorological processes on widely different space and time scales. The dispersion in itself is dependent on the local MBL turbulence structure, while on larger and longer space and time scales, the fate of constituents are determined by the mesoscale flow that arise from the very different surface forcing at the coast, dependent both on different surface types and terrain-height differences.

The objective of this study is to compare and quantify the potential for aerosols generated over land, often from antropogenic sources, to be transported out over the coastal ocean and *vice versa*. This includes finding out to what extent the marine aerosols propagate over land in regions where the coastal flow is determined by the interaction between the marine atmospheric boundary layer and a mountainous coastline.

APPROACH

Much of the progress of this project depends critically on data sets on coastal flows that have become available during the last few years. This includes data from the Swedish Baltic Sea coast, collected by the PI, while working at the Department of Earth Sciences, Uppsala University, and data from the US west coast, collected by Drs David Rogers and Clive Dorman at the Scripps Institute of Oceanography, La Jolla, California as a part of the Coastal Waves 1996 project.

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It has become clear that analysis of such data can be greatly augmented by the analysis of specific flow events using numerical models. Meteorological simulations of coastal flows have thus been performed both with the Swedish MIUU mesoscale model for coastal California (the PI and Dr Branko Grisogono, both at Stockholm University) and for Blekinge on the Swedish coast to the Baltic Sea (the PI and MSc Ragothaman Sundararajan, the latter at Uppsala University). In addition, the Penn State/NCAR MM5 mesoscale model was used to generate a data set of the entire June - August 1996 coastal California flow, coinciding with the Coastal Waves experiment (Dr Darko Koracin, Desert Research Institute (DRI), Reno, Nevada). The Us Navy COAMPS model will also be utilized – the PI spent a four-month sabbatical leave at NRL Monterey early in the year 2000 to acquire knowledge on how to set up and use this model system.

Flow realizations from model data is used to both study specific events in detail and to generate to a more general picture, e.g. using the MM5 database. One tool to facilitate this is the LAP-model, a random-walk trajectory model developed at DRI. Full dispersion calculations with the fully dynamically coupled tracer transport package in COAMPS will also be utilized for case studies. In the latter, simplified but realistic source functions for e.g. marine aerosols will be used in numerical simulations to assess the transport mechanisms on time-scales from hours up to days. Some of this work will be performed in collaboration with Dr Steven Burk, Naval Research Laboratory, Monterey, California.

WORK COMPLETED

Simulations based on data from the Coastal Waves 1996 experiment was performed starting already during 1997, focussing on the Cape Mendocino area. In a first experiment, an actual case study of the flow on 7 June 1996 was accomplished (Tjernström and Grisogono 2000). In a later study, the forcing and the terrain were manipulated to elucidate important mechanisms (Tjernström 1999). Then, simplified terrain analogs were used to carry this study further in the mesoscale model (Söderberg 1999, Söderberg and Tjernström 1999, 2000a). Analysis of several flow types has also been performed directly using the experimental data (Ström et al. 2000, Ström 1999, 2000a, 2000b).

The LAP-model, which is a so called “random-walk trajectory model” developed at DRI, was implemented in Sweden and selected cases from the MM5 database of flows from summer 1996 was studied (Sundararajan et al. 1999, 2000). This first study focus on an event of three days during the Coastal Waves 1996 field program, 26-28 June 1996. During this time the typical downcoast flow was interrupted while the near coast flow veered to onshore and then upcoast, and later back to downcoast. We assumed a distribution of particle sources all along the California coast, and study the transport of marine air both as a function of time, using a 6-to-12 hour window, and as a function of space along the coast, for these different flow regimes (Sundararajan et al. 2000).

RESULTS

Data from the Coastal Waves 1996 project was analyzed focussing on supercritical flow exemplified by 7 June 1996. This results from a local enforcement of a northerly along-coast jet, which is sufficiently strong to generate a supercritical flow for typical PBL depths (Tjernström and Grisogono 2000). Only in cases where the background free troposphere synoptic-scale flow was from the south causes the northerly jet to be sufficiently weakened that the local MBL flow becomes entirely

subcritical (Ström et al. 2000). Subsequent simulations were the terrain was modified by removing the terrain at Cape Mendocino, or by removing the cape all together, showed significant deviations from the classical shallow-water theory (Tjernström 1999), and prompted even more idealized runs, where the actual terrain was replaced by highly idealized easily manipulated runs (Söderberg 1999, Söderberg and Tjernström 1999, 2000a, 2000b, 2000c). Some main results from all these studies are:

1) Supercritical downcoast flow induces an expansion-fan at Cape Mendocino, with a drastic reduction in PBL depth and an increased wind speed while the jet becomes detached from the local coast south of Cape Mendocino. This process is regulated – as expected – by the angle of the coastal turn away from the flow. Thus, a larger angle generates a wider expansion fan, a larger the acceleration and a shallower MBL, south of the cape.

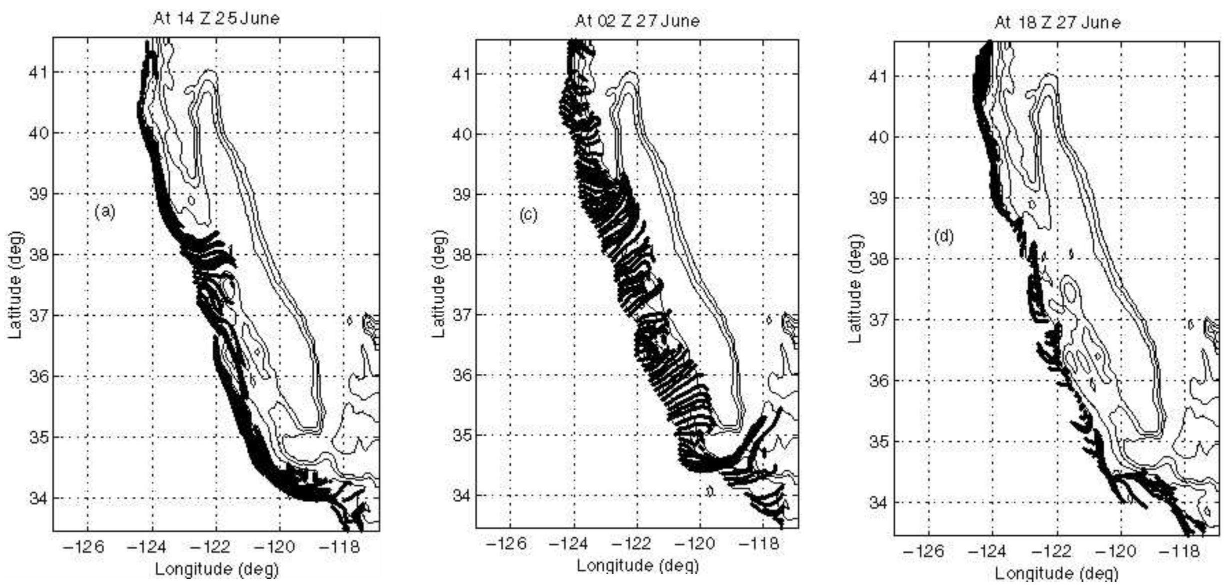
2) This generates a region, between the coast and the jet, with a value of the curl of the surface wind-stress vector is large. An analysis of the observed SST indicates that south of the cape this is responsible for the observed upwelling. The atmospheric flow is, however, relatively insensitive to the effects of the upwelling. In runs with and without the observed SST depression downstream of Cape Mendocino, the model results are insignificantly different. Thus there is little feedback between the ocean and the atmosphere for these conditions;

3) The abrupt transition at Cape Mendocino is to a large degree determined by the cross-flow oriented terrain at the cape. This terrain causes two things: a) A single buoyancy wave is excited in lee of the terrain, which is a main factor in controlling the collapse of the PBL within the expansion fan; b) The upstream flow north of the cape is partially blocked by this terrain, so that most of the flow acceleration occurs downstream of the cape. Thus, in simulations without the cape terrain, the flow starts to accelerate gradually even upstream of the cape, also when it is supercritical. In idealized runs without a cape, terrain height variations along the coast enhance the flow acceleration, while the terrain height is reduced along the flow direction.

4) The deviations from classical shallow-water theory, i.e. the gradual rather than abrupt transition from upstream unaffected to downstream expansion wave flow, is likely due to the temporal variations during realistic flows that includes a diurnal cycle. Thus the daytime afternoon flow is the strongest, supercritical everywhere, while the nighttime flow is weaker, transcritical – subcritical flow upstream and supercritical downstream of the cape. The temporal adjustment of the flow is rapid while supercritical, but slower in the transcritical mode. Thus, the gradual acceleration upstream of an abrupt change in coastline orientation (without a cape) is set up during the night, when the flow is transcritical. The duration of the daytime supercritical flow is not sufficiently long for a true steady state. The observed abrupt transition is thus believed to be due more to processes at the cape terrain (see above) than to supercritical flow dynamics.

Simulations with the LAP-model using meteorological fields on three selected consecutive days from the MM5 simulation of the summer of 1996, illustrates distinct situations when particles released over the ocean will remain in the marine environment for a long time – see below. This is the case for both up and down coast flow, more in the first than in the latter. In the case study, first the meteorological model is validated against observations from buoys, surface stations and radiosoundings. The the particle model is applied to simulate the time-dependent particle dispersion from many coastal locations.

For downcoast flow conditions, most of the cross coast transport occurs at favored locations, such as in bay areas (San Francisco and Monterey) and where the terrain is lower (southern central coast). The Ekman turning of the near-surface along-coast flow enhances the flow across the coast. In upcoast flow, the same mechanism acts in the other direction, and very little cross-coast transport occurs. In transition period, the weak onshore flow causes the marine air (here illustrated by particle trajectories) to cross into the San Jouaquin Valley very easily by crossing the coastal mountains on a broad front. The next step in this process will be to utilize the same modeling strategy on the entire month of June 1996, to establish a cross-coast mixing potential "climatology".



Particle positions from a 6-hour continuous release for thre episodes illustrating three regimesof coastal summertime flowalong the Californa coast. Leftmost shows typical summertime downcoast flow, with cross-coast transport at select locations, middle shows transport during a transition event when the coastal flow is relaexd and righmost shows atypical upcoast flow after the transition

IMPACT/APPLICATIONS

This project attempts to combine the study of small-scale atmospheric dynamics and the study of its impact on atmospheric transport. The dynamics study improves the understanding of the small-scale structures of coastal weather that are difficult to routinely forecast. For example, the apparent self-similarity of the Froude number patterns in supercritical flow past headlands may be used to interpret results from courser model output for local wind speed extremes.

Some properties of the coastal marine air, e.g. the presence of aerosol and low clouds, are detrimental to remote sensing based on electromagnetic radiation. A better understanding of processes that generate poor visibility conditions or the patterns of cloudiness and the possibility of such air to penetrate inland is useful in designing sensor systems of importance to the Navy. Better model predictions of such limitations can improve the base for tactical decisions.

TRANSITIONS

These results have been utilized in the continued analysis of the data from in particular the Coastal Waves program. Comparisons with model results from COAMPS have prompted an active collaboration between this group in Sweden and NRL Monterey (Dr Stephen Burk), at Scripps in further analyzing the turbulence structure (Dr Ian Brooks) and comparing with extensive shallow-water model simulations (Dr Kate Edwards).

The PI spent a shorter sabbatical at the Naval Research Laboratory in Monterey, January through April 2000, in order to learn how to use the COAMPS model in these and similar studies. During that stay various aspects of the California/Oregon coastal flow was studied with the model, i.e. the diurnal interaction between expansion fans from neighboring capes and the COAMPS representation of marine stratocumulus clouds. The aim is to implement COAMPS in Sweden; however, this has not yet taken place due to administrative difficulties in getting permission to use US Navy software in a non-US country.

RELATED PROJECTS

This project has become an integral part of the Coastal Waves 1996 experiment, co-sponsored by ONR and NSF. It also is part basis for current planning of a NSF-sponsored experimental coastal meteorology project currently planned by Dr Clive Dorman and Dr Ian Brooks at SIO. This project has also been closely linked to Swedish coastal atmosphere projects in relating local wind fields for the Swedish Wind Energy Program for offshore based "Wind Farms".

It also forms a basis for the modeling component of a European Community sponsored program on the atmospheric transport and deposition of nutrients to the coastal ocean, MEAD (coordinator Dr Tim Jickells, University of East Anglia in UK, and Dr Gary Geernaert, DMU in Denmark), as part of CAPMAN under the umbrella of Eurotrac-2 projects.

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